EVALUATION AND CORRELATION OF SOME PROPERTIES OF COAL

A thesis submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology
in
Mining Engineering

By

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CERTIFICATE

This is to certify that the thesis entitled **“EVALUATION AND CORRELATION OF SOME PROPERTIES OF COAL”** submitted by **Mr. Vishal Anand, Roll No. 111MN0426** and **Mr. Mrinal Giri, Roll No. 111MN0390** in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Mining Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by them under my supervision and guidance.

To the best of our knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date

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ABSTRACT

Mining is one of the oldest profession in world. The development and enrichment of society and mankind have experienced a direct relationship with it. The excavation of mineral resources comes with its complexities. The advancement of knowledge and technology have helped to address a lot of issues, yet many challenges remain because of the uncertainties in the earth materials. One of the major challenges is to select the right tool. Typically the selection of tools depend on the characteristics of earth materials. Rock mass is highly heterogeneous. Investigations and research in the field of rock mechanics and applied geology help in evaluating the influence of basic rock parameters such as strength, durability, crushability, etc. in effective mine designing and planning. There exists many approaches to correlate the different parameters of the rock mass so that the major influencing parameter can be predicted from a few other parameters that require relatively inexpensive processes at insitu conditions.

This investigation was an attempt to determine a few strength parameters of coal and develop interrelationship among those. Coal samples from six different surface locations are collected and their unconfined compressive strength, Brazilian tensile strength, point load index, slake durability, impact strength index as well as the moisture content values have been determined at laboratory. Unconfined compressive strength of rock material is a major parameter that influence the selection of cutting tool. Correlation between these parameters are developed statistically to find the best fit equation. Applicability of a few established criteria as Broch and Franklin (1972), Bieniawski (1975), D'Andrea et al. (1964), Cargill and Shakoor (1990), Rusnak and Mark (2000), Fener et al. (2005), Kahraman et al. (2012) and Altindag and Guney (2010) have been evaluated and the predicted values were compared with those obtained by the laboratory tests.

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CHAPTER-1

INTRODUCTION

1.0 Introduction

Mining is one of the fundamental activities of humanity for extraction of valuable and necessary geological materials from earth for the betterment of humanity. On the basis of nature of material mined, mining is broadly divided into two categories: Coal mining & Non- Coal mining. Mining involves basic procedures like prospecting of mineral deposit, estimation of ore reserve, feasibility and profitability analysis of mining operation, extraction of desired minerals and finally mine closure. Extraction of minerals from feasible deposits is full of uncertainties, rock characteristics is one of those. Evaluating rock parameters such as strength, durability, etc. have been of immensely important for the design of a safe mine.

1.1 Background of the Problem

Mining is one of the primeval activities that came into being since human's seminal period. Mining sector has always been a motivating force in our country's growth. It played a crucial role for the civilization to grow in all its form and acted as an ideal for the other sector of industries to breed. Though there have been many technological advancements in the field of mining, but still it remains a challenging activities. Extraction of mineral wealth from underground reserves is full with many intrinsic challenges and uncertainties. Coal mining is one such example. Mining also involves loosening of earth materials, the loosening process involves drilling, blasting, cutting, dressing of minerals materials. This requires need of cutting tools and heavy machinery optimized and engineered to meet the unpredictable nature of rock geology and properties. Often the tools used exhibit unexpected wear and tear as well as breakdown due to improper design and characteristics though every care is taken at the beginning. These phenomenon are due to heterogeneity of rock mass that comes up after initial excavation. Determination of influencing rock characteristics for the selection of tools are expensive, time consuming and involve complex process. Hence many attempts are made to correlate the major parameter to the parameters determined at field so that the tools can be optimized to suit the conditions.

This project is an attempt to review the knowledge base available as well as arrive at best possible correlation for evaluating coal parameters, thus helping in design and selection of better optimized tools for that particular insitu conditions. Compressive strength among the different mechanical parameters of rock is the most vital used in the mining operations. But in situ measurement of these parameters is not always possible as these are friable and much of these rocks cannot be made into the required sample specifications. Hence many correlations have been laid out to find major parameters from some minor parameters and indices. Also the evaluated parameters are compared with already established approaches. In this process coal samples from Gondwana Region are collected and test carried out to get different geotechnical parameters. In the end these parameters are correlated with each other and a viable relation between them is found out.

1.2 Aim of the study

The aim of the Project work was to predict the relation between different major rock parameters such as Uniaxial Compressive test, Tensile Strength test (Brazilian test) and some minor rock parameters like Point load Index, Impact Test Index, Slake Durability Test, Moisture content of coal of Mahanadi Coalfields Limited (MCL) and Central Coalfield Limited (CCL). It involves intensive experimentation on coal samples such as Uniaxial Compressive Strength, Tensile Strength, Slake Durability Index, Impact Test Index, Point load Index, and determination of their respective Moisture content. Investigation of correlation between them was also done. The goal was achieved by addressing the following specific objectives:

1.3 Specific Objectives

The following goals were achieved in this investigation.

1) Complete literature review on the topic to understand the problems associated.
2) Visit to mines and collection of samples.
3) Lab experiments to determine various engineering parameters of the samples collected were carried out.
4) Determination of Uniaxial Compressive Strength,
5) Determination of Tensile Strength (Brazilian Test)
6) Determination of Slake Durability Index
7) Determination of Point Load Index
8) Determination of Impact Test Index
9) Determination of Moisture Content of Coal
10) Developing correlation between the above parameters using statistical approach.
11) Comparison of the above developed correlation with previously established approaches.

The aim and specific objectives have been achieved by following a step by step scientific process outline in figure 1.1.

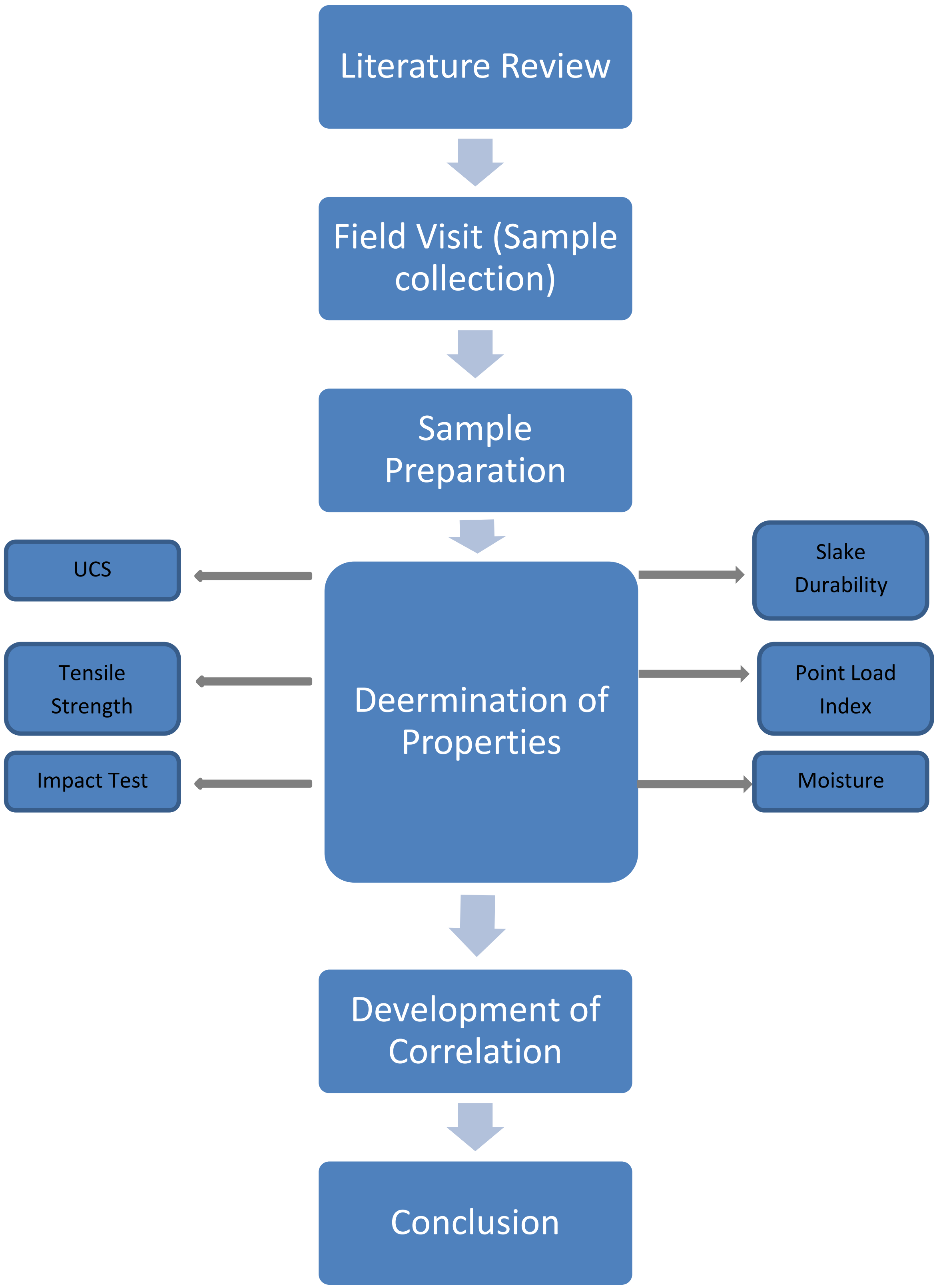

Figure 1.1: Flow chart of the Methodology Adopted

The aim and objectives were achieved by following a scientific approach including sample collection, testing and analysis. The project integrates all of those. Chapter one gives the background and objectives of the investigation. Chapter two encloses a detailed literature review about the sampling and tests to be carried out. Chapter three showcases the methodology followed with step by step approach. Chapter four defines the materials and testing procedures involved the investigation. Result and Analysis are given in chapter five including a detailed discussion on the outcomes obtained. At the end conclusions have been drawn and are given in chapter six with further suggestions.

CHAPTER-2

LITERATURE REVIEW

2.0 Introduction

All over the world, different investigators, scientist and researchers have investigated, assessed and evaluated the mechanical properties of coal and their correlation with stability and design aspects of coal mines. These parameters play a decisive role in qualifying the intrinsic properties of a coal specimen safe and the planning process of a mine. The investigation was carried out with understanding of many materials. Many resources such as published journals, articles, books, magazines as well as unpublished reports and theses were comprehended. The literature review covers different aspects of the topics that are discussed below.

2.1 Properties of coal

Coal is a sedimentary rock typically developed by natural geological processes by application of pressure on the dead matter. These processes make coal a heterogeneous material. Its properties vary widely with depth, distance as well as locations. The different properties that influence its behavior are as below.

2.1.1 Mechanical Properties of coal

- Unconfined Compressive Strength
- Slake Durability Index
- Joint Testing
- Tensile Strength (Brazilian Test)
- Direct shear or punch test

2.1.2 Intrinsic Properties of coal

- Moisture Content
- Density
- Porosity
- Sonic Testing

2.1.3 Index Testing

- Point load Index
- Schmidt hammer
- Shore hardness
- Swelling Index

2.2 Factors affecting mechanical properties of coal

The factors that affect strength, durability and hardness of the coal specimen are discussed below. Some are discussed in the methodology section.

2.2.1 Granular rock material

Grain shape, grain size, packing proximity, packing density, degree of meshing, type of contacts, quantity and type of cement and matrix (if existing) and mineralogical arrangement are one of the several characteristics that have been examined to predict the engineering performance of rocks.

2.2.2. Inherent grain size

Finer-grained deposits are more vulnerable to failure and at higher-rates than coarse-grained alluvial materials. The wrong way round, even though there are differing verdicts, fine-grained samples can endure upper uniaxial compressive loads. The likely cause for this is the amount of grain to grain contacts is higher for fine-grained samples. Therefore the applied external force is dispersed over a bigger contact surface.

2.2.3. Shape of grains and grain boundaries

Several investigators reported optimistic correlation between the uniaxial compressive strength and proportion of angular grains. Rocks made of smooth-edged grains are more resilient because crystals or grains with sharp edges are susceptible to a greater degree of scratch during the slake durability test, resulting in lower slake durability indices. Liable on the amount of attachment between the grains, such angular shaped particles may deliver a great meshing thus increasing the compressive strength.

2.2.4. Mineralogy of grains

Due to its abundance as a rock forming mineral, most of the correlations established by previous investigators take into consideration the quartz portion only. While not openly specified in the literature, it is our certainty that rocks composed of quartz grains should have a higher resilience due to the higher resistance of this mineral to mechanical scratch.

2.2.5. Extent and mineralogy of bonding at points of grain contact

Bonding governs the easiness with which macro fractures can spread through the sample by disturbing the assembly and breaking the bonds inside the groundmass. Mineralogy of bonding or cementing material is an important property that controls hardness, durability, and strength. Quartz provides the strongest binding followed by calcite and ferrous minerals. Clay binding material is the weakest. Among published material, Bell (1978) reported that the strength increases proportionally with the amount of cement. We believe that type of cement and degree of bonding are more important factors than the total percent of cement alone.

2.2.6. Packing density

Bell (1978) correlated packing density, which is the space occupied by grains in a given area, with the uniaxial compressive (UCS) and tensile strengths (BTS) of Fell Sandstone. He showed that strength increased with increasing packing density.

2.2.7. Size of the sample

There exists a relation between the length and diameter of sample that produces a correct strength. Usually cubical coal specimen are used in place of cylindrical samples because of the difficulty in obtaining an accurate L/D ratio of 2.5 to 3. Two representative samples of similar shape but different sizes will exhibit different strength values.

2.2.8. Shape of the sample

The shape of the sample plays a decisive role in determining the strength value of a coal specimen. Usually for testing of strength in coal, it is made into either cylindrical or cubic sample. For identical cross sectional areas, the circular (cylindrical) sample will exhibit higher strength value than the square (cubic) sample.

2.2.9 Rate of Loading

The load application rate can vary the strength value of identical samples widely. With slower load application rate, the sample will undergo creep and the strength value obtained will be much lesser than anticipated. High rate of loading exhibit a higher failure load that overestimates the strength.

2.2.10 Environment

Many factors such as temperature, moisture content, etc. influence the strength value of rock specimen. High temperature adversely affect the UCS value. Presence of moisture content also affects the strength value of a rock specimen to a great extent. Two identical samples (one being dry and other wet) prepared from the same rock, tested at similar condition will exhibit different strength values. The reason behind this is reduced cohesion due to increased moisture content.

2.3 Previous Investigations

The compressive strength parameter of the coal is a major input data for the design of excavation as well as the selection of excavating tools. However the determination of compressive strength not only need elaborate coring preparation but also skillful operation and testing. Typically it is carried out in a well-established laboratory which is often time consuming. Researchers have developed many tests as indirect tensile strength, point load strength, impact strength, slake durability that can be carried out with inexpensive portable instruments at field and those can be related to the strength of coal. There exists many correlations developed by researchers to predict the compressive strength with other parameters. As discussed below.

Sheraz et al. (2014) evaluated various relationships between UCS and Point Load Index (PLI) of Dolerite and correlation coefficients were developed through statistical analysis. They have shown all three functions (power, exponential and linear) that showed increase in value of Point load increase in the value of UCS in all three function the value R was very high. They have also shown the correlation of UCS with Compression wave velocity of Dolerite. They developed following equation

$$UCS = 110.1\ Is + 89.87\ (R = 71\%)$$

$$UCS = 85.52e^{0.718\ Is}\ (R = 67\%)$$

$$UCS = 202.71\ Is^{0.633}\ (R = 80\%)$$

Nazir et al (2013) carried out Unconfined Uniaxial Compression Test, Indirect Tensile Strength, Uniaxial compression test, Brazilian Test of limestone samples from different places by referring previous research work and found out correlation between UCS and BTS (Brazilian Test). They have given a correlation between UCS and BTS as below

$$UCS\ (MPa) = 9.25 * BTS^{0.947} \text{ with value of } R^2 = 0.9$$

Nuri et al. (2012) carried out different test on limestone, Sandstone and Gypsum like Unconfined Compression Test, Point Load Test, Tensile Strength (Brazilian Test) and Bending Test. These tests were done both in wet and dry condition to get better result. They correlated Point load and UCS in wet and dry condition and developed a linear relation between them. The correlation was also done between Tensile strength and point load in wet and dry condition and a linear correlation was developed between them. They found that the conversion factors in dry condition for all the rocks tested was less than that in wet condition.

Kahraman et al. (2012) found linear relation between UCS and BTS (Brazilian Test) with value of R^2 as 0.5 for different rock types including limestone. The ratio between UCS and BTS was 10.61. They have given the correlation as follows

$$\text{UCS (MPa)} = 10.61 * \text{BTS}$$

Farah (2011) carried out UCS and BTS test for weathered limestone and found out linear relation between them with value of R^2 as 0.68. The Correlation equation was follows

$$\text{UCS (psi)} = 5.11 * \text{BTS} - 133.86$$

Altindag and Guney (2010) found power relation between UCS and BTS for different rock types including limestone. They got the value of R=0.89 and the equation was

$$\text{UCS (MPa)} = 12.38 * \text{BTS}^{1.0725}$$

Yagiz (2010) collected three types of limestone and four types of travertine from south west Turkey. He developed relationships between the slake durability and Vp, E, modulus of elasticity, Schmidt hardness, water absorption by dry, saturated unit weight and UCS of seven types of carbonate rocks. He did slake durability for 10 cycle and the highest correlation coefficients of slake durability developed with UCS in 4th cycle (i.e Id_4) with value of r = 0.94. He also correlated slake durability of 1st cycle with 2nd, 3rd, 4th and 5th cycle and got very strong relation was established with r > 0.97 in each case. Following correlation equation were developed

$$\text{UCS} = 29.63\ Id_4 - 2858\ (r = 0.94)$$

$$Id_2 = 1.430\ Id_1 - 42.97\ (r = 0.99)$$

$$Id_3 = 1.814\ Id_1 - 81.39\ (r = 0.98)$$

$$Id_4 = 2.129\ Id_1 - 112.98\ (r = 0.97)$$

$$Id_5 = 2.441\ Id_1 - 144.11\ (r = 0.97)$$

Akram and Bakar (2007) carried out correlation between UCS and $I_{S(50)}$ for two group of samples Group A (Jutana Sandstone, Baghanwala Sandstone, Siltstone, Sakessar Massive Limestone, Khewra Sandstone and Dolomite) and Group B (Dandot Sandstone, Sakessar Nodular Limestone and Marl). They have also carried out Statistical Analysis of the results. They developed a linear relation between UCS and $I_{S(50)}$ for both Group A and Group B samples as below

For Baghanwala Sandstone, Jutana Sandstone, Sakessar Massive Limestone, Siltstone, Khewra Sandstone and Dolomite (Group A)

$$UCS = 22.792\ I_{S(50)} + 13.295$$

For Sakessar Nodular Limestone, Dandot Sandstone and Marl (Group B)

$$UCS = 11.076\ I_{S(50)}$$

Fener et al. (2005) found out correlation between UCS and point load and found out they were linearly dependent

$$UCS = 9.08\ Is + 39.32$$

Rusnak and Mark (2000) carried out Unconfined Compressive strength and Point load index of different kind of rock sample and found out following correlation

For coal measure rocks:

$$UCS = 23.62\ I_{S(50)} – 2.69$$

For other rocks:

$$UCS = 8.41\ I_{S(50)} + 9.51$$

Koncagul and Santi (1998) predicted correlation between UCS and Slake Durability of Breathitt shale stone. They developed relation between second slake cycle and UCS of as below:

$$UCS = 658*ID2 + 9081\ (r = 0.63)$$

However they arrived at a value of r = 0.63, i.e., 40 % variability. The probable reasons for 40 % variability ($.63^2$) were tensile nature of slaking, complex nature of rock intrinsic properties such as grain size, microstructure, porosity and interlocking of grains.

Cargill and Shakoor (1990) found dependence of UCS and IS(50) by performing some test on Rock sample and they found the following correlation equation

$$UCS = 13 + 23\, I_{S(50)}$$

Brook (1985) given "Size Correction Factor" (f), which can be used to find out point load index of 50 mm diameter ($I_{S(50)}$) for sample of any diameter De. The formula containing the Size Correction Factor (f) was

$$I_{S(50)} = f.\, F/\, D^2e$$

Where

$$f = (De/50)^{0.45}$$

And

F = Applied Load.

De = Equivalent Core Diameter.

f = Size Correction Factor.

Hassani et al. (1980) performed the point load test on large specimens and revised the size correlation chart commonly used to reference point load values from cores with differing diameters to the standard size of 50 mm. With this new correction, they found the ratio of UCS to $I_{S(50)}$ to be approximately 29.

Bieniawski (1975) found out the correlation between UCS, Is and the core diameter (D).

$$UCS = (14 + 0.175\, D)\, I_{S(50)}$$

Broch and Franklin (1972) found that the uniaxial compressive strength is approximately equal to 24 times the point load index for 50 mm diameter cores. They also developed a size correction chart so that core of various diameters could be used for strength determination.

$$UCS = 24\, I_{S(50)}$$

D'Andrea et al. (1964) performed uniaxial compression and the point load tests on a different variety of rocks. They found the following linear regression model to correlate the UCS and $I_{S(50)}$.

$$UCS = 16.3 + 15.3\, I_{S(50)}$$

CHAPTER-3

METHODOLOGY

3.0 Introduction

The main objective of this investigation is to correlation major and time consuming parameters from minor and simpler properties of coal. Many a times it is tough to prepare and test samples for complex time consuming properties of rock such as UCS. An exhaustive literature review was carried out to understand the aspects of excavation process, its efficiency and influencing parameters of mining operations. This was followed by collection of the data from the field. Specimens from many sample points were collected and carefully packed and sent to the laboratory for test and analysis. After the laboratory testing of samples collected proper statistical analysis was done and correlations were arrived at.

3.1 Sampling

The coal samples were collected from opencast projects. Coal blocks of volume around 1 cubic feet were handpicked from freshly exposed surface after blasting. They were dusted off for any loose material and kept sealed in bubble wrap to prevent any further contamination from air. The color of samples varied from black to slight grey. Some samples were friable and highly cleated.

The samples were collected from Talcher Area, Ib valley Area of MCL and Hazaribagh Area of CCL. The sample collection areas were approximately 500 km apart.

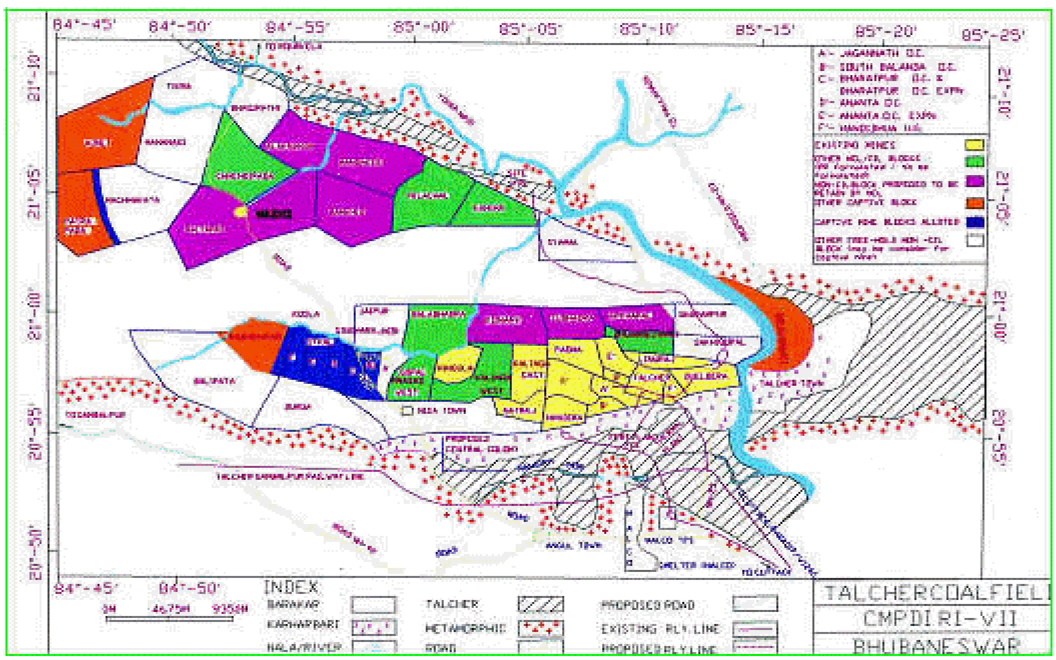

Figure 3.1:- Map of Talcher Coalfields (http://www.mcl.gov.in/images/talcher.gif)

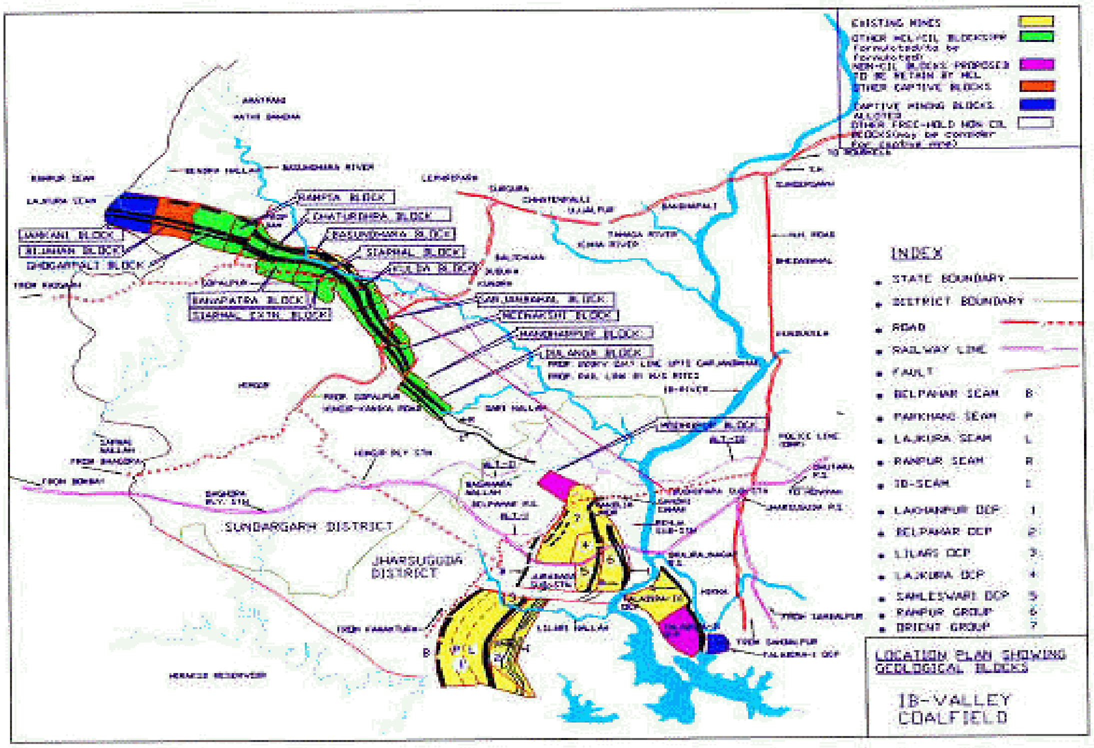

Figure 3.2:- Map of Ib Valley Coalfields (http://www.mcl.gov.in/images/ibval.gif)

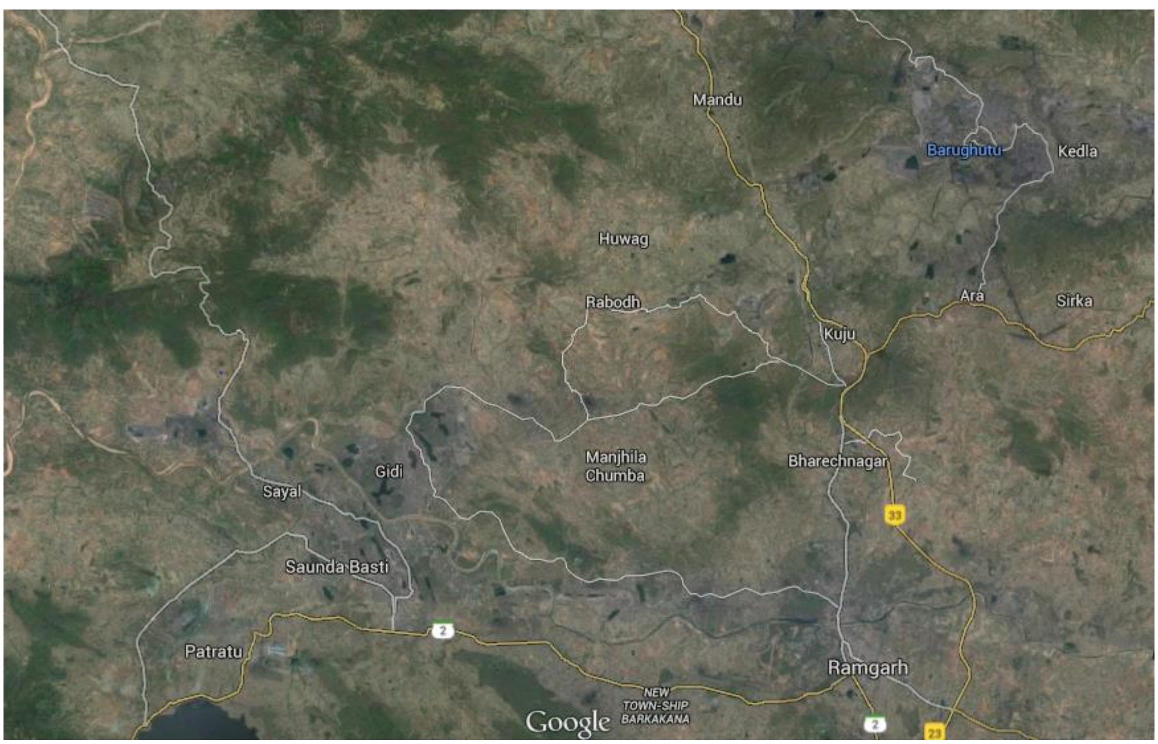

Figure 3.3:- Map of Hazaribagh Area (Central Coalfields Limited) Source: Google Maps

3.1.1 Significance

The quantity of moisture of the specimen at the time of the sample preparation can have important outcome upon the strength and deformation characteristics of the rock. The, shape, dimensional and surface tolerances of rock core samples are vital for defining rock characteristics of intact samples. This is exclusively true for strong rocks. Therefore numerous tests are carried out to define the strength factors of the rocks and evaluate its deformation characteristics. So that the measured circumstances and amount of moisture in the specimen remaining intact during laboratory analysis. There may be reasons for analysis of samples at other moisture contents, from saturation to dry. So it's better to know the moisture conditions so it can be controlled correctly.

Coal cores are the sample of record which gives the measured prevailing insitu conditions and at that specific borehole position. Laboratory rock test sample preparation procedures of rock core from block samples for strength and deformation testing are defined. The time period of storing is dependent upon the character, importance of the insitu conditions the type of laboratory testing planned to be carried out on the samples. The samples are anticipated to yield important suggestions about the geological, physical, chemical and engineering character of the underground for use in the design and building of an engineered assembly. The core samples need to be well-kept using precise techniques for a specified time interval so that it can reveal the authentic insitu environments.

Coal cores always need to be managed and conserved such that their characteristics are not changed in any way due to mechanical mutilation or changes in ambient situations of moisture and temperature or other environmental factors.

- The coring of the block could be vertical, horizontal, or angled.
- This practice covers the rules, necessities, and measures for core drilling, coring, and sampling of rock for the purposes of site investigation.
- The values that are given in inch-pound are taken as standards while the values which are mathematically converted to SI units are not to be taken as standard.
- This practice applies to core drilling in hard and as well as soft rock.
- Persons with proper awareness and expertise of using the tools to perfect use should be involved in carrying out this process.

- This practice does not support to expansively address all of the methods and the issues accompanying with coring and selection of rock.

3.1.2 Storage

- The samples collected were kept and stored in a particular space.
- Samples collected were kept in Bubble wrap bags encased in cardboard boxes.
- Bubble wrap bags were used to protect it from moisture and the atmosphere gases.
- Cardboard boxes were used to store them and protect from mechanical damage.

3.1.3 Transportation of Samples

- The samples were transported in train and taxi to prevent any damage to them from vibration and jerks.
- Coal blocks were stored in Bubble wrap bags which provided protection to the specimen and stopped reaction of the coal with the atmospheric air.
- Cardboard boxes also protected them from moisture in the air and reduced the probabilities of defective specimen in the laboratory testing.
- During the transporting, Cardboard boxes are usually preferred because they protect the coal samples from sunlight.
- Cardboard boxes preserved the true nature of the samples from the site to the laboratory along with the bubble wrap bags

3.2 Coring:

For sample preparation of UCS and Brazilian Test, cylindrical samples of L/D ratio required were 2.0-2.5 and 0.5 respectively. So the coal blocks were loaded on the platform and clamped in position using nuts and bolts. And finally coring was done with water as lubricant and dust prevention. Water also prevented overheating of the drill bit during coring. The whole core preparation process was done as per ASTM D4543 (American Society for Testing and Materials)

Figure 3.4:- Coring of Coal Block using Drilling Machine

3.3 Testing

The most important scope in rock mechanics is measuring and determination of rock properties and behavior by using the suggested testing methods, techniques, and conditions. These include the engineering characteristics of rock such as its strength, mode of deformation, mode of failure, and modulus of elasticity, sonic velocity index, tensile strength etc. A study upon rock in rock mechanics is one of civil and mining subject disciplines. Rocks are inhomogeneous and anisotropic in nature and though it is collected from the same places it still shows variations in properties and nature. Generally there are two common categories for testing of rock samples:

- Laboratory testing which is done at the lab with the rock samples obtained from the selected locations,
- Field or In-situ testing which is done by operating directly at the site itself.

3.3.1 Laboratory Testing

For the determination of the various rock strength characteristics, indices and other parameters which define the nature of the rock, laboratory testing is done. The samples are gathered from the site and are properly conserved for laboratory testing so the true nature of the rocks is not changed. As stated before, the two most common methods of laboratory testing for rock are:

1) Index test and Indirect Strength test;

2) Direct or Strength test.

3.3.1.1 Index Test and Indirect Strength Test

Index test can be administered in a limited manner and is comparatively simpler in nature. However it does not provide fundamental property. The devices used are normally portable and simple which also allows the test to be conducted at on-site. The results obtained are just an index on parameters that are being tested. The sample preparation for the indirect strength test and the Index test are easy to prepare and less time consuming as compared to direct strength tests. The data obtained from the testing does not provide thorough information about the planning of structures but is useful in its pre-assessment and conveying valuable statistics for the viability of the configuration. The tests for Index and Indirect Strength test include:

- Uniaxial compressive strength test
- Slake durability index test
- Brazilian or Indirect tensile strength test
- Point-load index test
- Sonic wave velocity test

3.3.1.1.1 Point-Load Index Test

One of the quickest and simple test to conduct, the rock sample can be in irregular block or core. The equipment has easy handling and usability as test could be perform directly on field.

3.3.1.1.2 Slake Durability Index Test

For the determination of the disintegration nature of the rocks the slake durability test is one of the most useful techniques when it is subjected to consecutive cycles of drying and wetting conditions along with movement. This test properly simulates the measured weathering behavior of rocks in the field.

3.3.1.1.3 Brazilian or Indirect Tensile Strength Test

The objective of this test is to measure uniaxial tensile strength of rock sample indirectly using Brazilian test.

3.3.1.1.4 Direct Test or Strength Test Direct

Direct Test or Strength Test Direct test includes point by point test planning and precise finishing of the specimens. The testing itself includes advanced and huge equipment critical to the point by comprehensive testing strategies and may oblige complex examination and this is additionally costly. Being of time consuming nature, these test are heavily dependent on the sample preparation and the technique of test being evaluated and the tools and equipment used in testing. The quantities of tests are made restricted because of the expensive testing strategies and the information and results got can be utilized directly for planning purposes. On the other hand, the information got is the fundamental basic property and would be the immediate presentation of property being assessed. The tests for Direct or Strength test include:

- Permeability of rock
- Modulus of deformation
- Uniaxial and Triaxial compressive strength test
- Shear strength test

3.3.1.1.5 Uniaxial Compressive Strength Test

Samples were prepared and tested in accordance with ASTM D2166/D2166M. Uniaxial compressive strength (UCS) of coal and deformation behavior under loading is verified by applying compressive load until failure occurs in the core by a fracture in the middle using high capacity Universal testing machine (UTM). The sample take around 8-10 minutes for complete failure.

3.3.1.2 Field or In-situ Testing of Rocks

The testing approach is to assess the rock properties and nature at the site scene where it is found. It will include large-scale of direct strength test on site as the preparation and the equipment involved in testing could be expensive, complex, and time-consuming. In-situ strength tests are undertaken when properties of rock are very critical to the design and detailed assessment under the actual environment is considered essential. The cost involved in undertaking the test can be seen in the anticipated behavior of the unstable block with regards to nature of the project and the surrounding of rock mass.

The testing methodology is to survey the coal properties and nature at the field where it is found. In-situ strength tests are attempted when properties of coal are exceptionally discriminating to the outline and definite appraisal under the genuine environment is viewed as crucial and considered important. It will incorporate vast size of direct strength test on location as the readiness and the equipment included in testing could be costly, complex, and takes too much time to evaluate the test. The expense included in undertaking the test can be seen in the expected conduct of the unsteady block as to nature of the venture and the insitu environment of rock mass.

The main advantages of field testing are:

- Samples involved are of large scale and include bigger discontinuities and joints
- The in-situ sample resembles the field conditions and represent the conditions prevalent there more closely.

The disadvantages of the insitu testing are

- It is almost impossible to carry out these tests in the field itself.
- Many a times, the insitu samples are too friable and it’s not possible to make samples from them.

CHAPTER-4

EXPERIMENTATION

4.0 Introduction:-

This chapter covers the procedure for different test, Size of sample required for the testing and priority of testing.

4.1 Size of sample Required For Different Tests:-

Test	Size of sample
UCS	L/D = 2-2.5
Tensile Strength (Brazilian Testing)	L/D = 0.5
Point Load Testing	L/D = 1-1.5
Impact strength Index	(-)4.75mm to (+)3.35mm 50 grams of coal (each test)
Slake Durability Index	40mm to 60mm 50g (+,-5g)

4.2 Procedure of Test:-

ASTM standards for each test were understood and followed for carrying out evaluation of different parameters of coal samples collected. Each test was done with three samples and an average reading was taken to compensate for any experimental, intrinsic fault in the specimen and human errors.

4.2.1 Point load testing

Point load test is the standard index text for measuring the strength of rocks in the field. Irregular samples having ratio of 2:1 for longer axis to shorter axis can be sued for the test. ASTM D5731 was referred during the sample preparation and testing of coal specimens for point load index. The sample is kept between the pointed platens and the load is applied gently but steadily. The load at failure in kg divided by the square of the distance between the platens in cm gives the point load index (Is).

Figure 4.1:- Point Load Testing Machine before loading of sample

Figure 4.2:- Point Load Testing Machine after loading of sample

For measuring the strength of coal in the field, point load test is one of the principle techniques. Irregular samples having proportion of 2:1 for length to breadth was used for the test. The specimen was kept between the pointed platens and the hydraulic pressure is given slowly however uniformly the load at failure in kg divided by the square of the distance between the platens in cm gives the point load index (Is).

The initial Diameter and length were measured and sample was prepared taking average of 3 reading.

- The length to breadth ratio was determined.
- The sample into point load machine was placed into the machine and load applied along the diameter till failure occurs.

$$\text{Point Load Index (PLI)} = \frac{P}{D^2}$$

Where, P=Failure load

D=Diameter of sample

4.2.2 Unconfined Compressive Strength Test

The cylindrical sample is placed at the center of the loading platen. The upper platen is adjusted carefully so that the platen just makes contact with the cylindrical sample. The gauge for measuring deformation is made zero or the initial reading is noted. The loading rate of the compressive load was 0.5 to 1.0 MPa/sec. The load, axial deformation and longitudinal deformation are noted at sufficient intervals. The load is increased steadily till the failure occurs in the sample. The failure load is noted and divided with cross sectional area of the sample to get the unconfined strength value of the representative sample.

Figure 4.3:- Unconfined Compressive Strength test after failure of coal specimen

4.2.3 Tensile Strength (Brazilian Testing)

The Brazilian tensile strength was conducted to determine the tensile strength of coal (ASTM D3967). Following steps were followed to determine tensile strength of coal:-

- The machine was set on the suitable measuring scale and proper rate of loading with the arrow set to zero.
- The diameter and thickness of coal sample were measured. (L/D = 0.5)
- The coal specimen was set between the lower and upper platens and they are brought near the coal specimen.
- The coal specimen was loaded at the prescribed steady state to the point of failure.
- The fracturing load (P) was recorded.
- Tensile strength of coal can be calculated by the formula given below

$$\text{Tensile Strength (in MPa)} = \frac{2P}{\pi D t}$$

Where P= Load at failure (in N)
D= sample diameter (in mm)
t=sample thickness (in mm)

Figure 4.4:- Brazilian Tensile Strength Test

4.2.4 Slake Durability Test

For assessing the influence of weathering on Rock and its disintegration, slake-durability test is regarded as one of the simplest test. However, the mechanisms leading to slaking of rock have not been fully comprehended even after so many years. The mechanisms of movements of the rocks inside the apparatus are understood but its effect on weathering is still unknown. . Franklin and Chandra indicated that ion exchange and capillary tension are responsible phenomena for the slaking action the wetting process may only take for parts of the rock within only ten minutes, particularly for the surface part but due to appropriate rotation speed and the level of the water most of the parts of the rocks get wet. The interchange of cautions and anions take place with the adsorption and absorption of water which makes the rock swell in size and slaking occurs in clay bearing rocks.

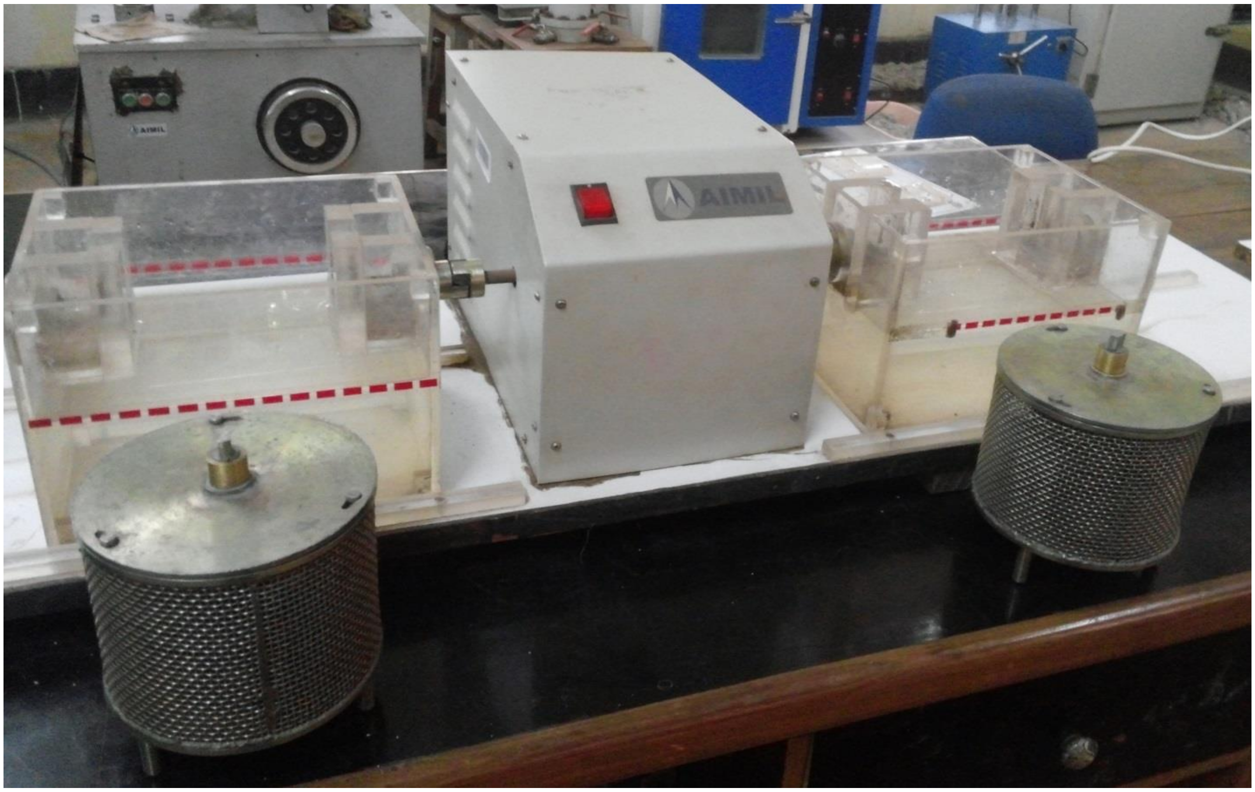

Figure 4.5:- Slake durability Test Preparation

Fig 4.6:- Slake durability Test coal samples

Water also plays a crucial role in altering the mechanical parameters of the rock. Upon saturation of rock with water, the capillary tension is reduced at grain contacts and the tips of cracks with significant increase in the water menisci within the pore of rocks. Fractures and cracks start developing inside the rock with increase of water content in pores, leading to weathering of rock. This is the commanding technique ruling the durability behavior of porous rock. Drum rotation is also involved in the constituent mechanism of slaking, not only the consecutive wet-dry cycles exposed to rock. Weight and shape of the specimens influence these mechanisms. Therefore any further analysis of the mechanism is not fruitful and the main focus is determination of slake durability index of the respective rock.

4.2.4.1 Method

For determining the resistance offered by a rock sample to weakening and fragmentation when subjected to three standard cycles of drying and soaking, the slake-durability test was done. The sample preparation and experimentation was done as per ASTM D4644.

- Two sets of drums of the length of 100 mm and the diameter of 140 mm were taken and ten coal specimens each having a mass of 40-60 g, with cumulative weight around 450-550 g were put inside it.
- The trough was filled with water upto the indicated level.
- The two drums were loaded in the trough and coupled with the motor and rotated.
- The rotation was driven by a motor capable of rotating the drums at a speed of 20 rpm, which was held constant for a period of 10 minutes.
- After slaking for the period of 10 minutes, these coal lumps were then dried in an oven at a temperature of 105 degree centigrade for up to 4 hrs.
- Finally, the mass of dried samples was weighted to obtain the first cycle. The test was conducted over three cycles, in which the weight of particles of 10 coal lumps retained in these wet-dry cycling tests was therefore determined.

Table 4.1:- Gambles' Slake Durability Classification (Goodman, 1980)

Group Name	% retained after one 10 min cycle (dry weight basis)	% retained after two 10 min cycle (dry weight basis)
Very High Durability	>99	>98
High Durability	98-99	95-98
Medium High Durability	95-98	95-95
Medium Durability	85-95	60-85
Low Durability	60-85	30-60
Very Low Durability	<60	<30

4.2.4.2 Method of Calculation

- Initial weight taken = A
- Weight after 1st cycle = B
- Weight after 2nd cycle = C
- Weight after 3rd cycle = D
- % retention after 1stcycle = (A-B)/A x 100
- % retention after 2nd cycle= (B-C)/B x 100
- % retention after 3rd cycle= (C-D)/C x 100

4.2.5 Impact strength Index (ISI):-

Under experimental conditions, this mechanism evaluates the crushability of coal.

- 50 grams of coal sample is taken.
- In the cylinder in which the sample is kept, a plunger is dropped from fixed height.
- The crushed sample is collected and is sieved through (+) 3.35 sieve.
- The weight of particle > (+) 3.35 mm give ISI in absolute numerical value.

Figure 4.7:- Impact Strength Unit (Cylinder with plunger) and Sample of coal

4.2.6 Moisture Content:-

About 1g of finely pulverized -212 micron size air-dried coal sample is weighed in a silica crucible and then placed within an electric hot air oven. It is maintained at 105ºC. The crucible with the coal sample is allowed to put in the oven for 1.5 hours and it is taken out with the help of tongs, then cooled in a desiccator for about 15 minutes then weighed. The determination of Moisture content of coal was done according to ASTM D2216. The loss in weight is reported as moisture (on percentage basis).

$$\text{Moisture Content (in \%)} = \frac{Y-Z}{Y-X} * 100$$

Where,

X = weight of empty crucible, in grams (gm.)

Y = weight of crucible + coal sample before heating, in grams (gm.)

Z = weight of crucible + coal sample after heating, in grams (gm.)

Y -X = weight of coal sample, in grams

Y- Z = weight of moisture, in grams (gm.)

4.3 Experimental Size

The investigation involved many tests to determine various engineering parameters of coal such as Unconfined Compressive Strength, Tensile Strength test (Brazilian test), Point load Index, Impact Test Index, Slake Durability Test and Moisture content. A large number of samples were tested for the purpose. The results and observations reported here reflect the average value of three to four samples for each test type except for Slake Durability test where two sample tests were carried out. A total number of thirty-six tests were done with about 102 samples (table 4.2 and 4.3).

Table 4.2:- Total number of Tests

UCS	BTS	Point load Index	Impact Test Index	Slake Durability Test	Moisture content
6	6	6	6	6	6
Total	36				

Table 4.3:- Total Number of samples Tested

UCS	BTS	Point load Index	Impact Test Index	Slake Durability Test	Moisture content
6X3=18	6X3=18	6X3=18	6X3=18	6X2=12	6X3=18
Total	102				

CHAPTER-5

RESULTS AND DISCUSSIONS

5.0 Introduction

The investigation evaluated the different strength parameters of the coal specimen. Different tests such as unconfined compressive strength (UCS), Brazilian Tensile Strength (BTS), Point Load Test, Slake Durability, Impact test, and determination of Moisture content were carried out. The following presents the test results and their analysis.

5.1 Tests

The investigation included many characterization studies as unconfined compressive strength (UCS), Brazilian tensile strength (BTS), Slake durability test, Impact Test, Point load index in addition to determination of moisture content. The reported results represent average values of three samples for each test type. A total of 110 samples were tested in this investigation.

5.1.1 Unconfined Compressive Strength

A total of eighteen cylindrical coal specimens representing six different location were tested for Unconfined Compressive Strength having L/D ratio of 2 to 2.5. The compressive strength value ranged between 9.72 and 28.5 MPa. The mean value was 16.67 MPa with standard deviation to be 7.1988 MPa. These values classify that the coal specimen low strength are of class E type according to Deere and Miller (1966). The elastic modulus values determined were between 0.189 and 1.32 GPa. The modulus ratios varied from 19.44 to 116.3 that confirms to its class L type (Deere and Miller, 1966).

Table 5.1:- Unconfined Compressive Strength of Coal Specimen

Sample ID	UCS (MPa)	E (MPa)	μ (Poisson's Ratio)
1	19.69318	1138.4062	0.36658
2	13.59392	496.7513	0.044498
3	28.50428	1321.886	0.911742
4	18.75281	1264.963	0.343822
5	9.751463	1134.991	0.678
6	9.722882	189.0033	0.117784
Mean	16.6697558	924.33347	0.410404
Stand. Dev.	7.1988555	466.43683	0.331305

5.1.2 Slake Durability

Slake durability test is an important parameter in predictive the stability of samples in extreme environment. A total of twelve tests were carried out for slake durability tests.

Table 5.2:- Slake Durability of Coal

Sample ID	Slake Durability Index 1st cycle	Slake Durability Index 2nd cycle	Slake Durability Index 3rd cycle
1	94.91	89.62	83.66
2	96.50	91.31	86.48
3	97.09	92.24	86.8
4	94.2	88.9	83.2
5	92.71	88.77	85.03
6	91.88	86.73	83.16
Mean	94.548	89.595	84.72167
Stand. Dev.	2.0504	1.96518	1.63632

All the samples exhibited very high (94.5%) slake durability index in the first cycle of operation. So more tests cycles were carried out. It was observed that the percentage retained after 2nd cycle was also very high (about 90 %). But when the same samples were subjected to third slaking cycle, some loss of materials was observed. The index decreased to 84.7 %. It shows the material is highly durable as per Gambles table (Table 4.1).

5.1.3 Point Load Index

A total of eighteen specimen representing six different locations were tested. The samples were irregular in nature. The Point Load Index values varied from 0.5282 to 1.08188, the mean value was found out to be 0.73755 and standard deviation 0.19985. (Table 5.3)

Table 5.3:- Point Load Index of coal

Sample ID	1	2	3	4	5	6	Mean	Stand. Dev.
Point load testing, Mpa	0.7502	0.5282	1.0819	0.8255	0.6486	0.59098	0.73755	0.19985

5.1.4 Tensile Strength (Brazilian test)

Eighteen specimen from six different locations were tested in laboratory for Brazilian test. The samples had L/D ratio of around 0.5. The Tensile Strength values varied from 1.0608 to 2.5025, the mean value was found out to be 1.495 and standard deviation was equal to 0.4075. (Table 5.4)

Table 5.4:- Tensile Strength of coal

Sample ID	1	2	3	4	5	6	Mean	Stand. Dev.
Tensile Strength, Mpa	2.113	1.8278	2.0608	1.577	1.501	1.3916	1.495	0.4075

5.1.5 Impact Index

Eighteen samples belonging to six different locations were tested and their impact index were evaluated. In each test, 50 grams of coal of size (-) 4.75mm to (+) 3.35mm were tested for Impact Index. The impact index values ranged from 15.67 to 31, the mean value was equal to 21.04 and standard deviation was found out to be 5.94889. (Table 5.5)

Table 5.5:- Impact Index of coal

Sample ID	1	2	3	4	5	6	Mean	Stand. Dev.
Impact testing	19.67	18	31	25.33	15.67	16.57	21.04	5.9489

5.1.6 Moisture Content:-

Moisture content of the matter has strong influence on the mechanical behavior. 1 gram samples from total of eighteen specimen representing six different locations were tested. The sample size selected was 212 microns and oven dried at 110^{o}C for 4 hours. The moisture content varied from 3.5 to 6.96 %, with the mean value to be 5.276 and standard deviation equal to 1.315. (Table 5.6)

Table 5.6:- Moisture Content of coal

Sample ID	1	2	3	4	5	6	Mean	Stand. Dev.
Moisture (%)	5.64	4.83	3.5	4.29	6.44	6.96	5.276	1.315

5.2 Development of Mutual Relation

One of the primary objective of this investigation was to develop mutual relationship between different parameters. This objective was achieved by carrying out regression analysis UCS vs Point Load, UCS vs Tensile Strength, UCS vs Moisture, Slake Durability vs Moisture, and Slake Durability vs UCS. Apart from determining the governing relation among parameters, the application of a few established equations were also evaluated. Those are discussed here.

5.2.1 Relation between Unconfined compressive strength vs Point Load (Figure 5.1)

It was observed that as the point load value of specimen increases, compressive strength values also increases. There is a strong correlation between the point load and UCS values. The mutual relation is given by the following equation

$$UCS = 44.764 * I_{S(50)} - 15.825; R^2 = 0.8204$$

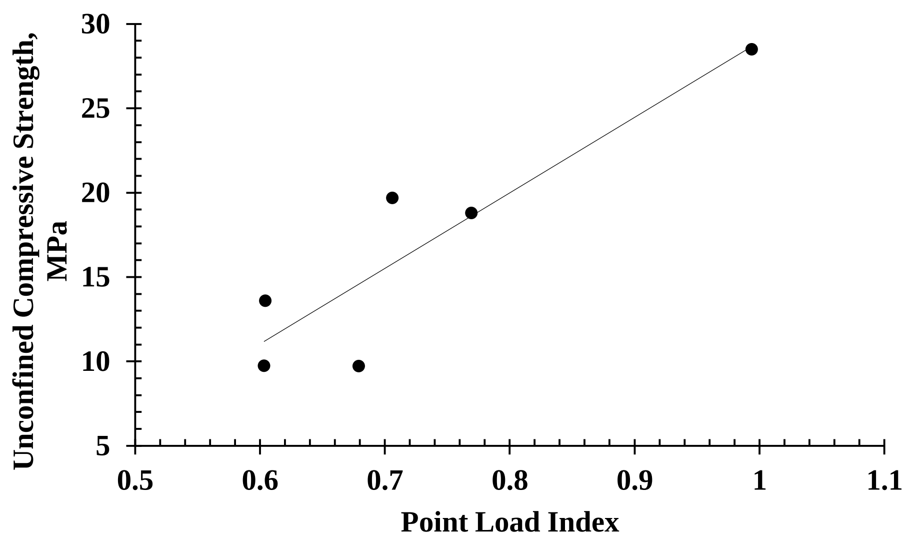

Figure 5.1:- Relation between Unconfined Compressive Strength and Point load

Point load testing was carried out with different equivalent diameters. The size correction to 50 mm diameter was carried by the equation given by Brook (1987):

5.2.2 Relation between Unconfined Compressive Strength vs Brazilian Tensile Strength (Figure no 5.2 and 5.3):

It was observed that the behavior of samples for unconfined compressive and tensile strength values exhibited similar trends i.e. they are directly proportional to each other. There exists a strong relation between them through the equation as below. The power relation between the UCS and point load has a better coefficient (about 8.5 %) more than that compared with the linear relation.

$$UCS = 18.432 * BTS - 15.492; R^2 = 0.5956 \text{ (Figure 5.2)}$$

$$UCS = 5.3511\ BTS^{1.982}; R^2 = 0.6422 \text{ (Figure 5.3)}$$

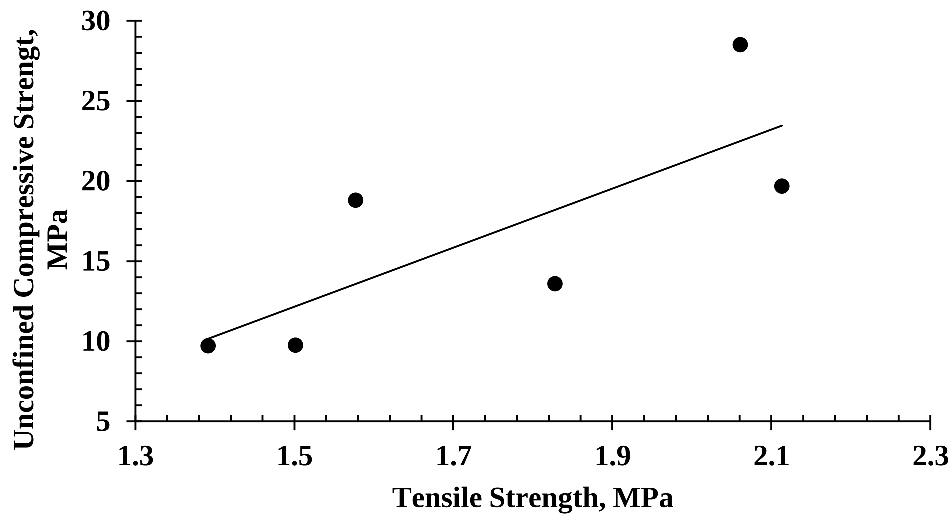

Figure 5.2:- Relation between UCS and Tensile Strength (Linear)

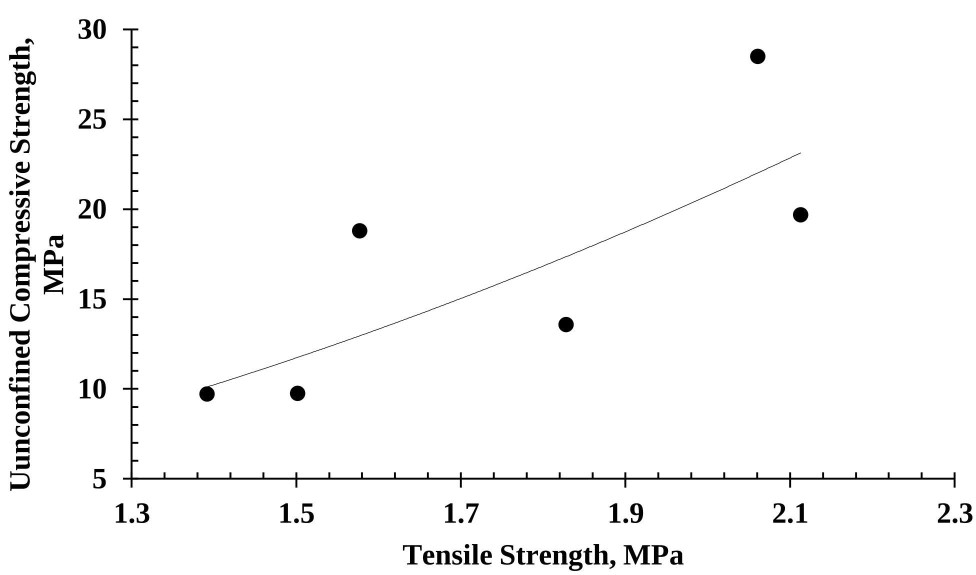

Figure 5.3:- Relation between UCS and Tensile Strength (Power)

5.2.3 Relation between Unconfined Compressive Strength vs Moisture Content (MC)

Mutual relation between UCS and Moisture was evaluated and it was observed that with increase in moisture, UCS value was decreasing. The correlation equation was as below: (Figure 5.4)

$$UCS = (-4.67)*(MC) + 41.319;\ R^2 = 0.7276$$

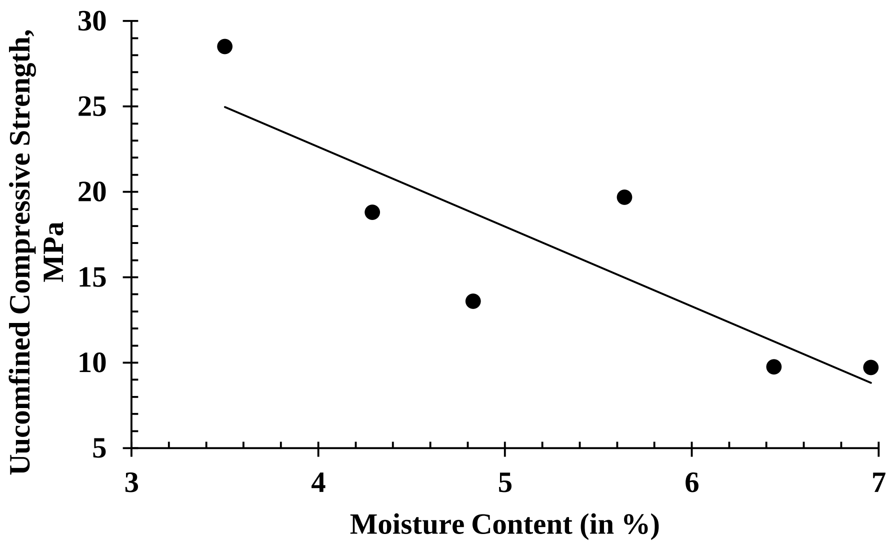

Figure 5.4:- Relation between UCS and Moisture Content

5.2.4 Relation between Slake Durability vs Moisture (Figure 5.5 and 5.6)

Each of three slaking cycles were correlated with the moisture content of coal and it was observed that the first and second cycle show a strong relation with the moisture content. With increase in moisture content, the Slake durability index fell. Following are the correlation found:

$$SD_1 = (-1.3346)*Moisture + 101.59;\ R^2 = 0.7329$$

$$SD_2 = (-1.2202)*Moisture + 96.034;\ R^2 = 0.6669$$

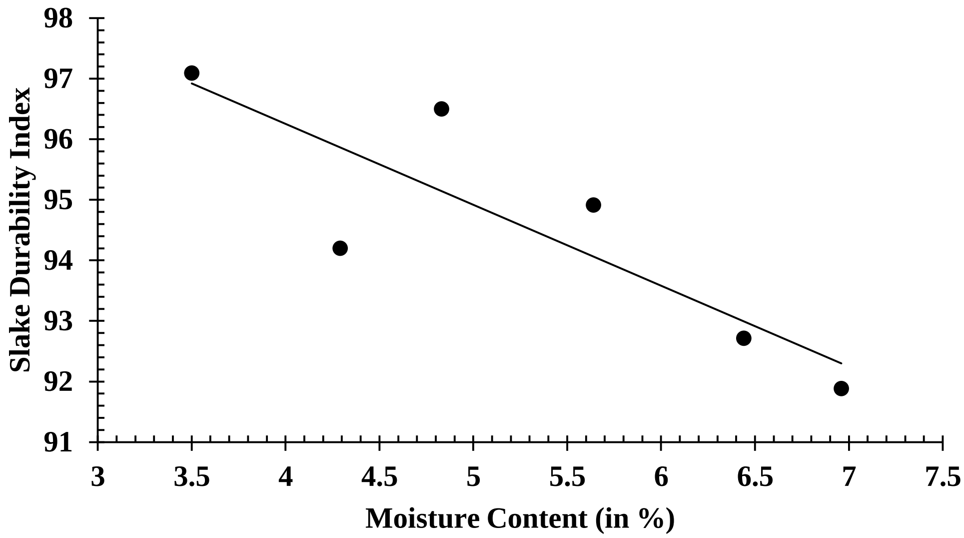

Figure 5.5:- Relation between Slake durability 1st cycle and Moisture Content

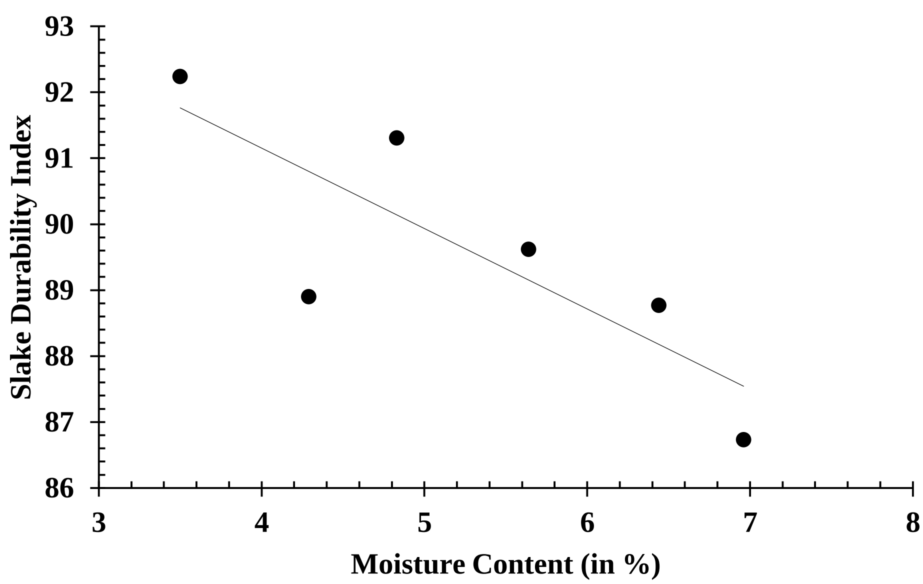

Figure 5.6:- Relation between Slake durability 2nd cycle and Moisture Content

5.4.5 Relation between UCS vs Slake Durability

Each of three slaking cycles were correlated with the UCS of coal and it was observed that all the cycles show a strong relation with UCS. In the first and second cycle, there was increase in UCS with increase in Slake durability index. However the trend was opposite in the third cycle, i.e., UCS decreased with increase in Slake durability index Strong relation between them was found as below: (Figure 5.7-5.9)

$$UCS = 2.6485 * SD_1 - 233.73;\ R^2 = 0.5688$$

$$UCS = 2.6009 * SD_2 - 216.35;\ R^2 = 0.5039$$

$$UCS = -1.2202 * SD_3 + 96.03;\ R^2 = 0.6669$$

The correlation dramatically improved at third cycle. This observation confirms to that by Yagiz (2010)

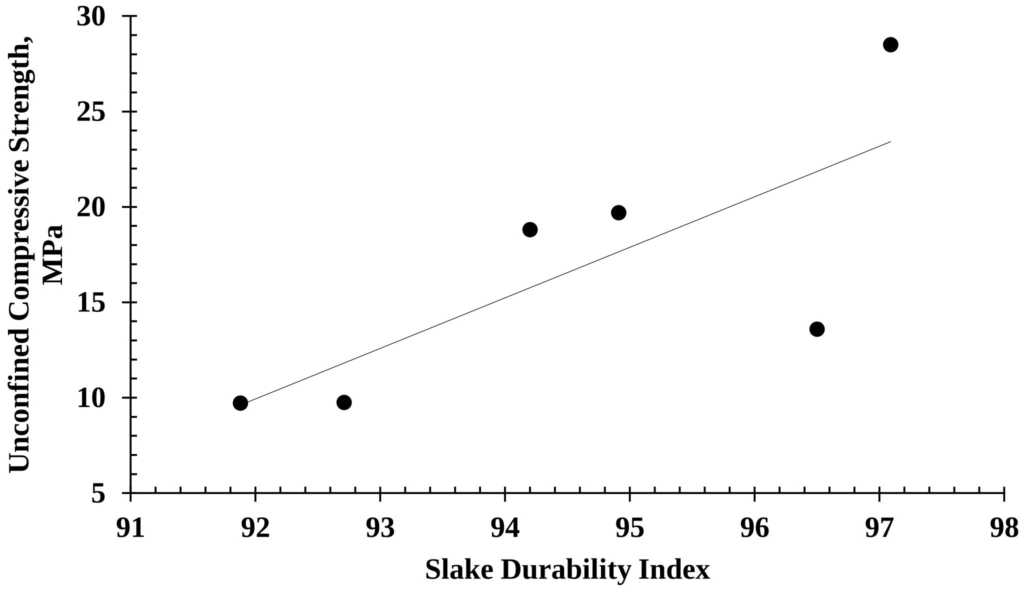

Figure 5.7:- Relation between UCS and Slake Durability 1st cycle

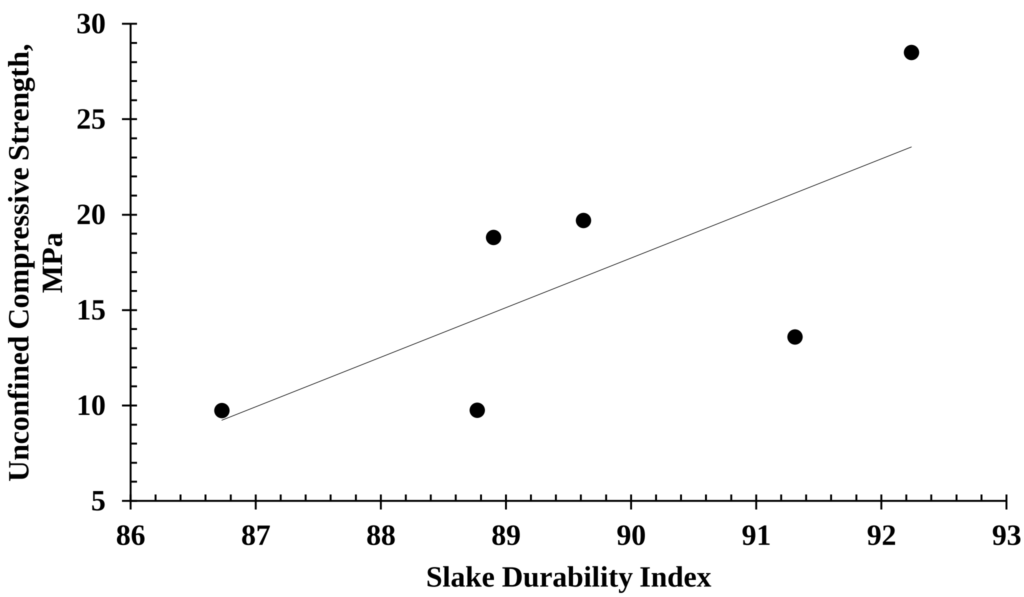

Figure 5.8:- Relation between UCS and Slake Durability 2nd cycle

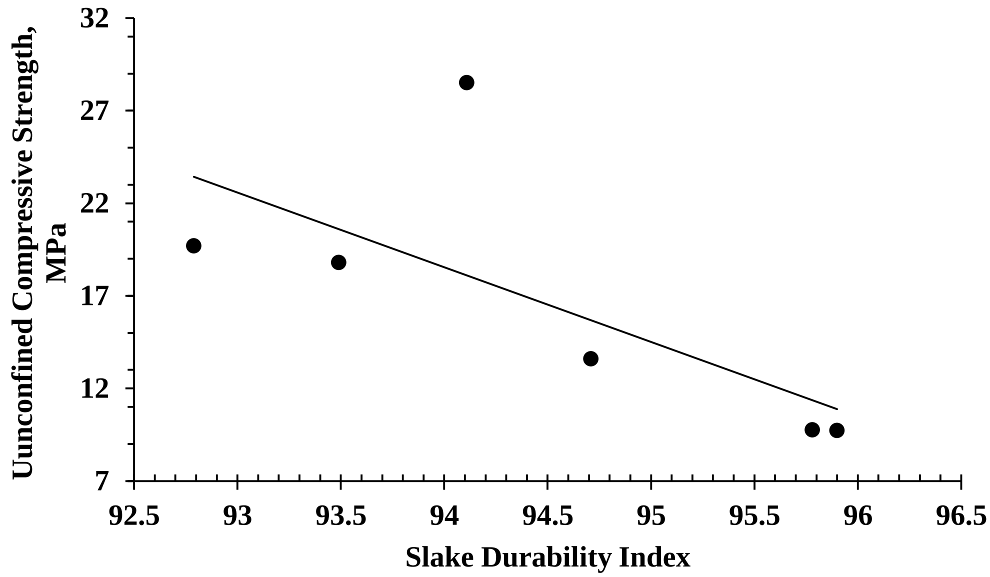

Figure 5.9:- Relation between UCS and Slake Durability 3rd cycle

5.2.6 Relation between Measured UCS vs. Predicted UCS

The measured point load test and tensile strength values of the coal samples from six different location were used in the established equations to predict the compressive strength values. Then the predicted compressive strength values were compared with the measured strength data. Those are discussed below.

5.2.6.1 Broch and Franklin (1972) proposed the below equation between UCS and Point Load Index.

$$UCS = 24 * I_{S(50)}$$

The measured values of Point Load Index were used in the equation to predict the UCS values. The predicted UCS values were compared with the measured one (Figure 5.10) It was observed that the measured values were more than the predicted. The Broch and Franklin equation is a little conservative as comparison to the measured values. The mutual relation between them is

$$\text{Predicted UCS} = 0.4398 * \text{Measured UCS} + 10.091;\ R^2 = 0.8204$$

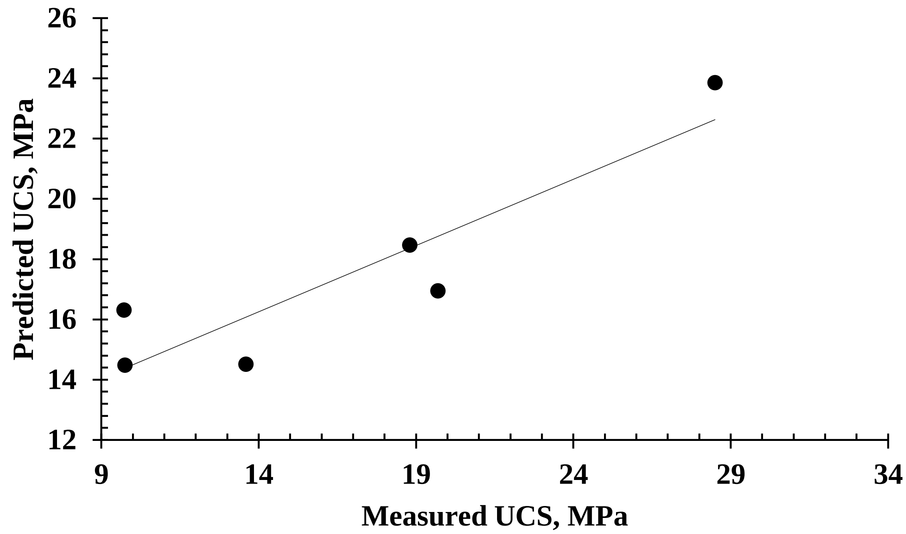

Figure 5.10:- Measured UCS vs. Predicted UCS by Broch and Franklin

5.2.6.2 Bieniawaski (1975) proposed the relation between UCS and Point Load Index as below

$$UCS = (14+0.175*D)*\ I_{S(50)}$$

The value of Point Load Index as measured in the laboratory tests of eighteen samples representing the six different locations were used to determine predicted UCS values. The predicted UCS values were compared with the measured UCS values (Figure 5.11). The measured values were more compared to the predicted one. The relation between Measured and Predicted UCS were found as below

$$\text{Predicted UCS} = 0.3739*\ \text{Measured UCS} + 9.2333;\ R^2 = 0.8764$$

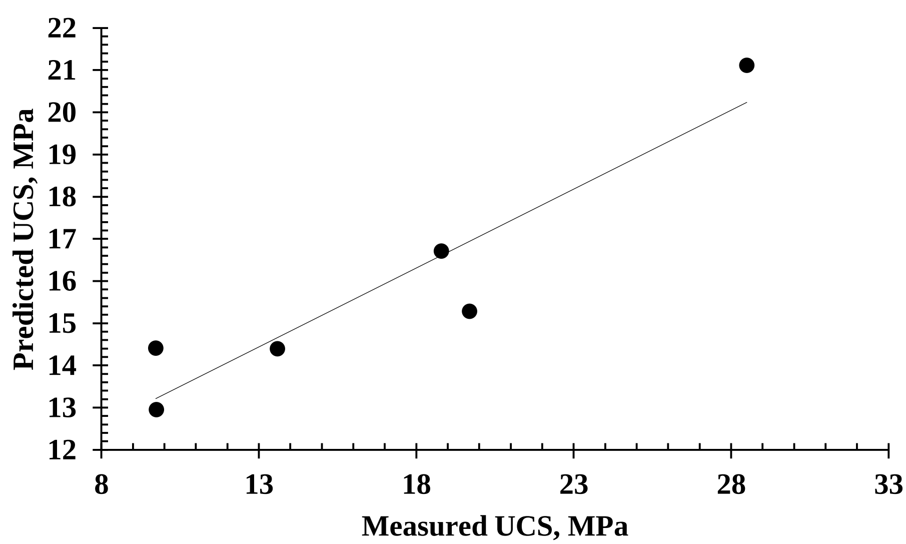

Figure 5.11:- Measured UCS vs. Predicted UCS by Bieniawaski

5.2.6.3 D'Andrea (1964) established the relation between Point Load index and Unconfined Compressive Strength as given below

$$UCS = 16.3+15.3* I_{S(50)}$$

The Point load Index valued were used to find predicted values of UCS and then compared with measured values of UCS (Figure 5.12). The measured values were less in comparison to the predicted one. The equation between Measured and Predicted was found to be

$$\text{Predicted UCS} = 0.2804* \text{Measured UCS}+22.733;\ R^2 = 0.8204$$

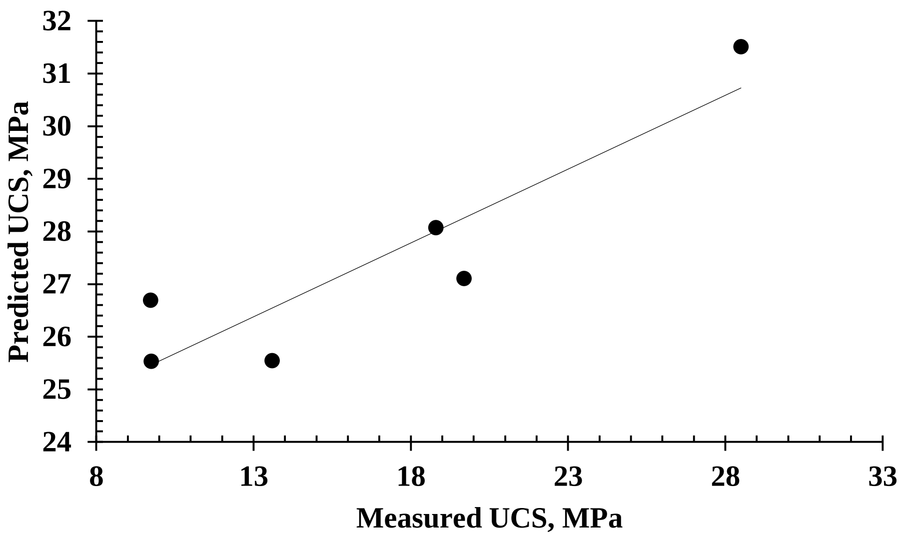

Figure 5.12:- Measured UCS vs. Predicted UCS by D'Andrea

5.2.6.4 Cargill and Shakoor (1990) proposed the following equation as the relationship between UCS and point load Index

$$UCS = 13+23* I_{S(50)}$$

It was observed that the predicted values of the UCS superseded the measured values. The Cargill and Shakoor equation overestimated the UCS values. (Figure 5.13) The following equation is the relation between predicted and measured values:

$$\text{Predicted UCS} = 0.4215* \text{Measured UCS}+22.67;\ R^2 = 0.8204$$

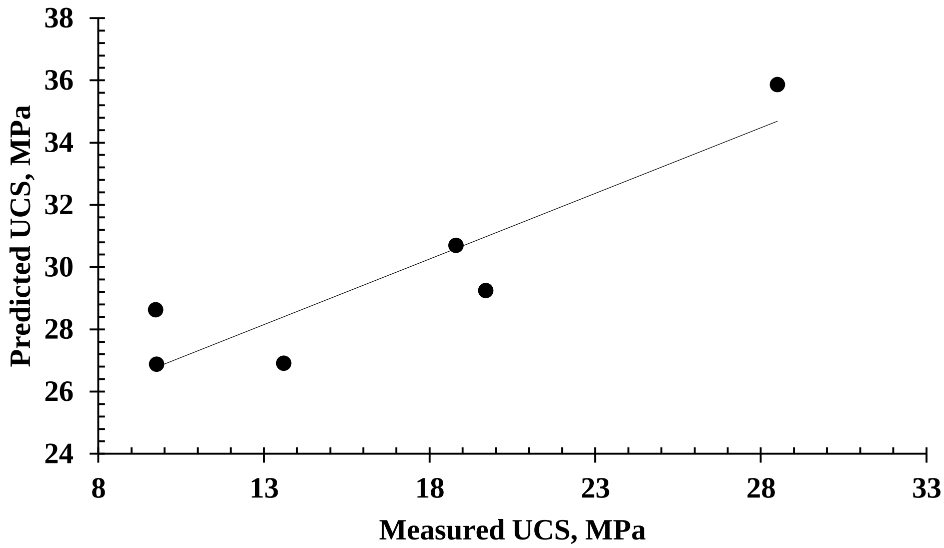

Figure 5.13:- Measured UCS vs. Predicted UCS by Cargill and Shakoor

5.2.6.5 Rusnak and Mark (2000) established the equation given below as the correlation between Point load Index and UCS.

$$UCS = 23.62 * I_{S(50)} - 2.69$$

Predicted values were lesser than the measured values. Hence it was concluded that the Rusnak and Mark equation underestimated the UCS values. (Figure 5.14) The equation given below is the proposed relation between predicted and measured UCS values:

$$\text{Predicted UCS} = 0.4329 * \text{Measured UCS} + 7.2412;\ R^2 = 0.8204$$

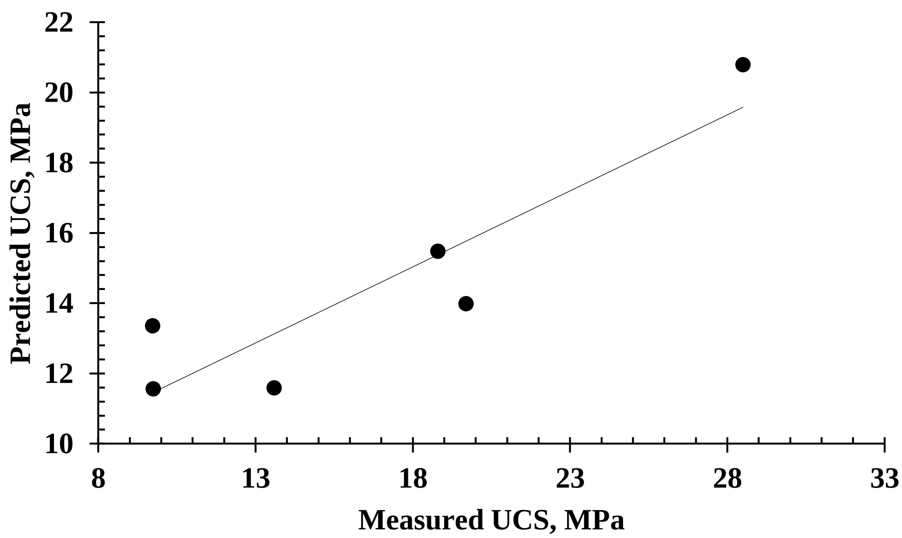

Figure 5.14:- Measured UCS vs. Predicted UCS by Rusnak and Mark

5.2.6.6 Fener et al. (2005) predicted the correlation between UCS and Point Load Index as the following equation:

$$UCS = 9.08* I_S + 39.32$$

It was observed that the predicted values exceeded the measured values. Therefore it was established that the Fener et al. equation overvalued the measured values of UCS. (Figure 5.15) The following equation gives the correlation proposed between predicted and measured values of UCS:

$$\text{Predicted UCS} = 0.1664* \text{Measured UCS} + 43.138;\ R^2 = 0.8204$$

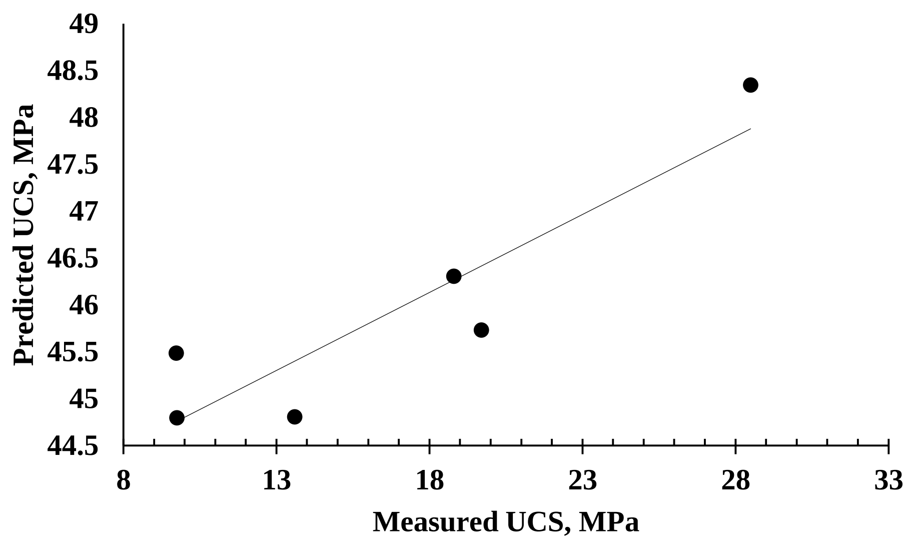

Figure 5.15:- Measured UCS vs. Predicted UCS by Fener et al.

5.2.6.7 Kahraman et al. (2012) predicted the relation between UCS and Brazilian Tensile strength as below

$$UCS\ (MPa) = 10.61 * BTS$$

The following correlation was found between predicted and measured values of UCS: (Figure 5.16)

$$\text{Predicted UCS} = 0.3428* \text{MeasuredUCS} + 12.8;\ R^2 = 0.5956$$

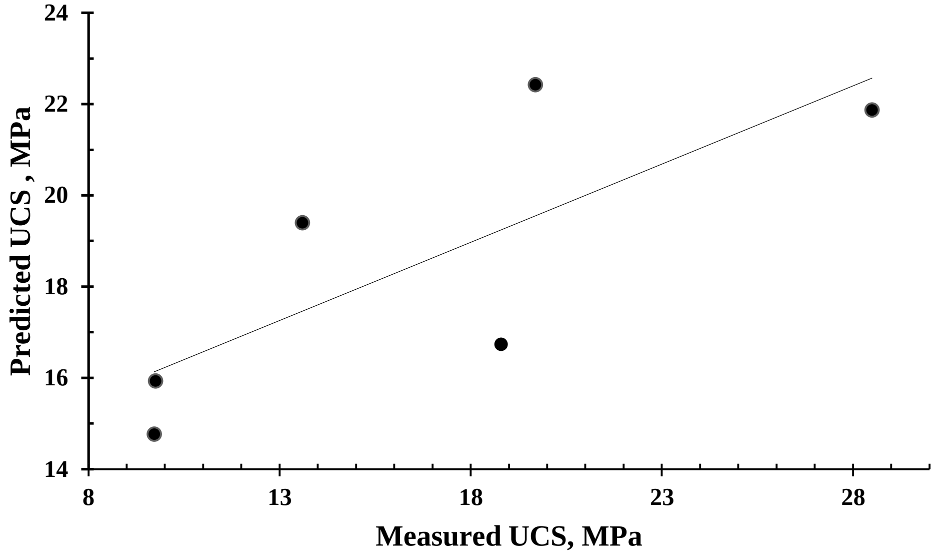

Figure 5.16:- Measured UCS vs. Predicted UCS by Kahraman et al.

5.2.6.8 Altindag and Guney (2010) established the equation given below as the correlation between Brazilian Tensile strength and UCS.

$$UCS\ (MPa) = 12.38 * BTS^{1.0725}$$

Using the value of tensile strength the value of predicted UCS was found. The correlation developed between the measured and predicted values of UCS is as per the following equation: (Figure 5.17)

$$Predicted\ UCS = 0.4469 * MeasuredUCS + 15.066;\ R^2 = 0.5956$$

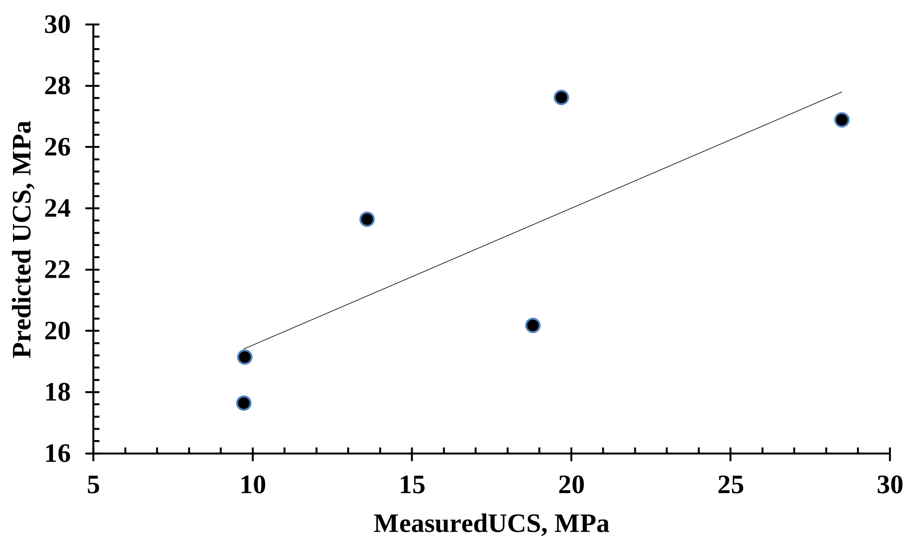

Figure 5.17:- Measured UCS vs. Predicted UCS by Altindag and Guney

CHAPTER-6

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This investigation was an attempt to determine the strength of coal samples and development of mutual relation among those. The coal samples from freshly exposed faces, were collected from six different active operating mines. They were packed, sealed and transported with care to the laboratory. Different properties such as Unconfined Compressive Strength, Tensile Strength test (Brazilian test), Point load Index, Impact Test Index, Slake Durability Test, Moisture content of coal were determined in the laboratory by following established procedures. Correlation between Unconfined Compressive Strength and Point Load, Unconfined Compressive Strength and Tensile Strength, Unconfined Compressive Strength and Moisture, Slake Durability and Moisture, and Slake Durability and Unconfined Compressive Strength were carried out. Relation obtained from Point Load test values and tensile strength values were used to predict Unconfined Compressive Strength using D'Andrea (1964), Broch and Franklin (1972), Bieniawaski (1975), Cargill and Shakoor (1990), Rusnak and Mark (2000), Fener et al. (2005), Altindag and Guney (2010) , Kahraman et al. (2012).

Based on these exercises, the following conclusions are made:

i. Coal samples collected belong to Gondwana Region
ii. The average Moisture Content is 5.277%.
iii. The average Impact Strength Index is 21.04.
iv. The average Tensile Strength is 1.861 MPa.
v. The average Point Load Index is 0.737 MPa.
vi. The average Unconfined Compressive Strength is 16.67 MPa.
vii. The Slake Durability Index for 1st cycle is very high (94%). There is 11.5 % mass decrease after 3rd slaking cycle.
viii. The relation between Point Load and Unconfined Compressive Strength is equal to UCS = 41.104* $I_{S(50)}$ -13.168.
ix. The relation between Tensile Strength and Unconfined Compressive Strength is equal to UCS = 18.432* BTS -15.492 and UCS = 5.3511 $BTS^{1.982}$
x. The best relation obtained between Unconfined Compressive strength and Slake Durability Index is UCS = -1.2202* SD_3 + 96.034 at 3rd slaking cycle.

The analysis between measured and predicted UCS exhibited best relation with that proposed by Bieniawaski (1975). The obtained equation was Predicted UCS = 0.3739* Measured UCS + 9.2333, $R^2 = 0.8764$.

The other approaches such as D'Andrea (1964), Broch and Franklin (1972), Cargill and Shakoor (1990), Rusnak and Mark (2000), and Fener et al. (2005) exhibited more or less similar realtion with correlation coefficient of 82%.

The approach by Kahraman et al. (2012) and Altindag and Guney (2010) produced more or less similar correlation coefficient at 59 % between measured UCS and that predicted by tensile strength data.

6.2 Recommendation

This investigation was an attempt to correlate measured parameters as point load and tensile strength to predict a major parameters as UCS. The exercise was however limited by many factors including time. It is strongly felt that the aim and objectives can be improved with more number of samples, experiments and analysis. That would also strengthen the applicability of those observations. It is recommended to cover more surface mining operations, to collect more number of samples and to carry out more number of tests and analyze the data for effective applicability.

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